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(54) LASER ION SOURCE

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H01J 27/24 (2006.01)
H01J 49/16 (2006.01)

(52) **U.S. Cl.**

CPC ***H01J 27/24*** (2013.01); ***H01J 49/161*** (2013.01); ***H01J 49/162*** (2013.01); ***H01J 49/164*** (2013.01)

(58) **Field of Classification Search**

CPC H01J 27/24; H01J 27/022; H01J 49/161; H01J 49/162; H01J 49/164; G21K 5/00; G21K 5/04

USPC .... 250/423 P, 492.3, 423 R, 424, 425

See application file for complete search history.

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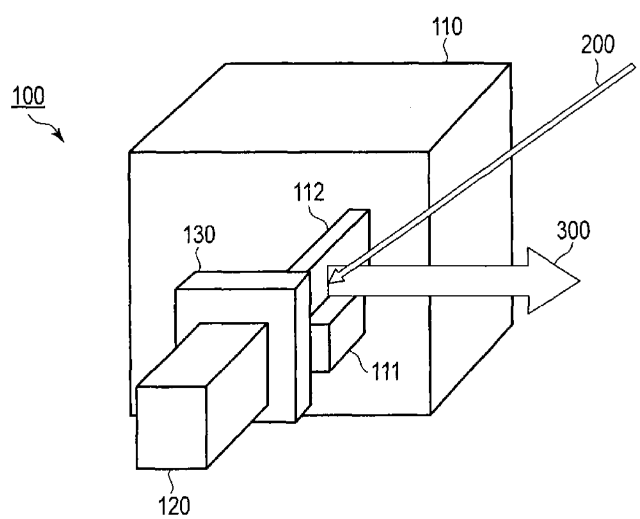
(57) **ABSTRACT**

According to one embodiment, there is provided a laser ion source. The laser ion source includes a vacuum chamber which is vacuum-exhausted and in which a target is transported and set, a valve which is opened when the target is transported into the vacuum chamber and is closed except for the transportation, a target supply chamber which holds the target to be movable, and a transportation unit which transports to the vacuum chamber the target held on the target supply chamber while opening the valve after the target supply chamber is vacuum-exhausted while closing the valve.

5 Claims, 3 Drawing Sheets



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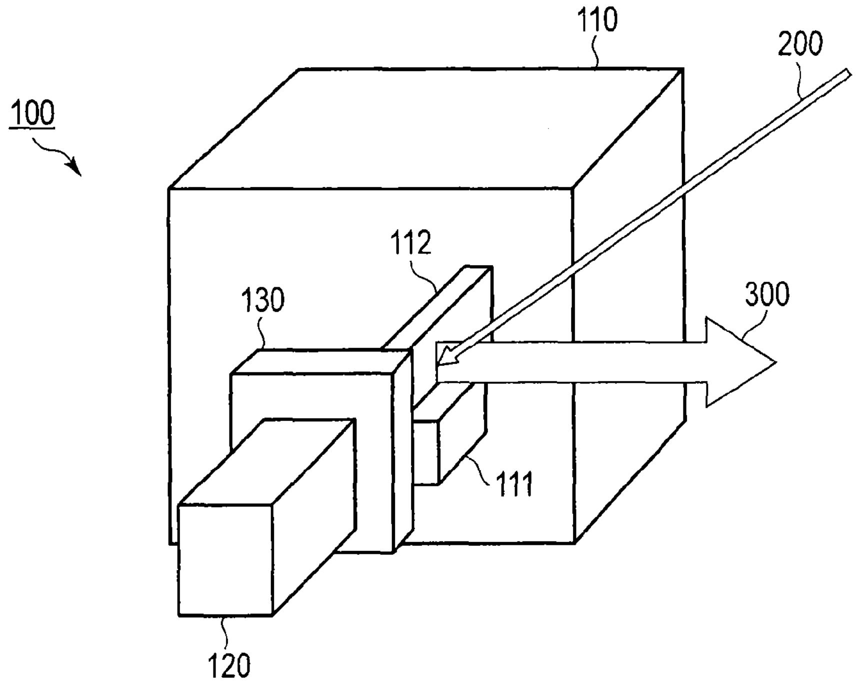
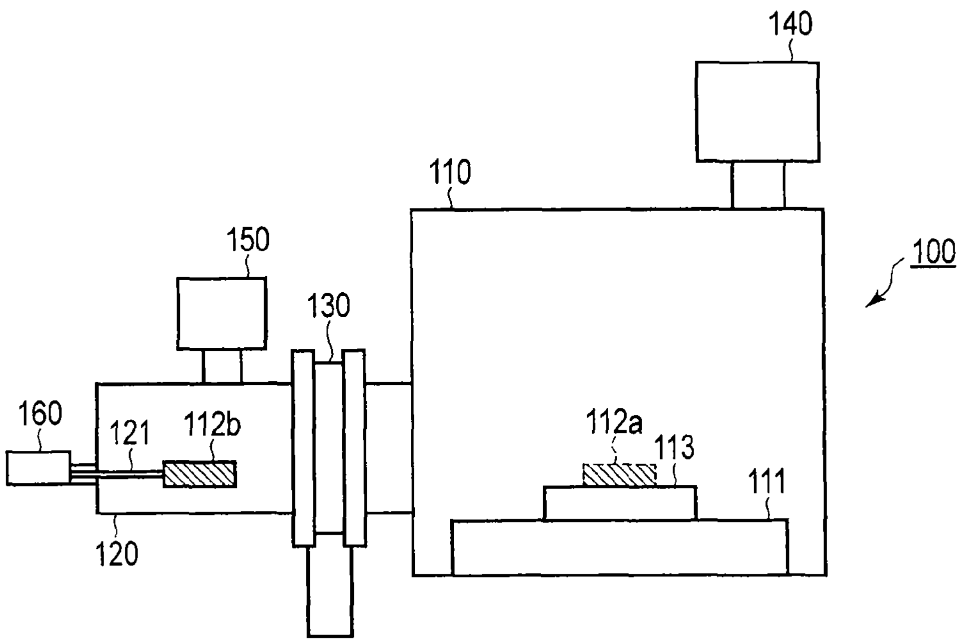

110
200
100
112
130
300
111
120

F I G. 1


140
110
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160
121
112b
112a
113
111
120

F I G. 2

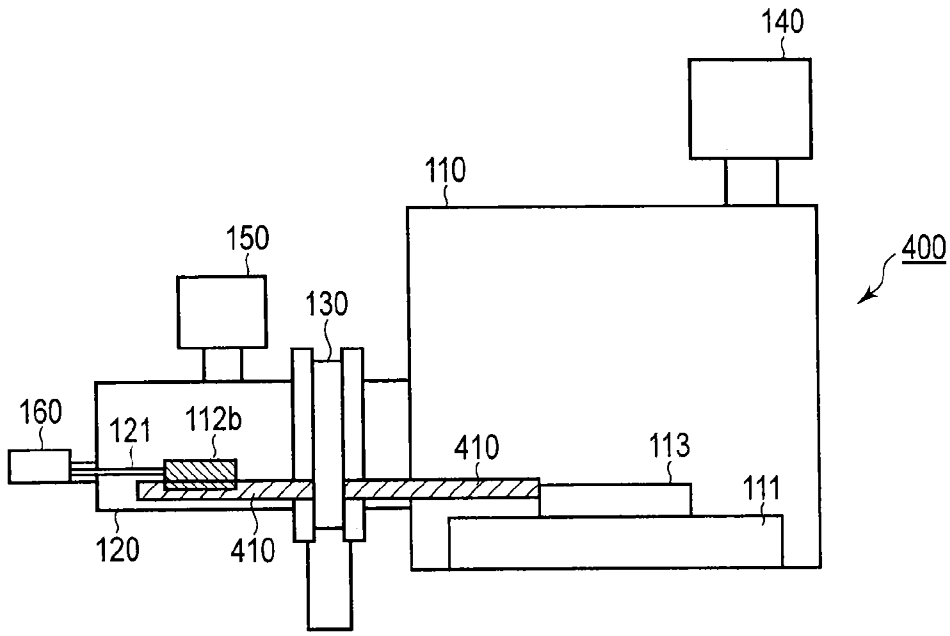


FIG. 3

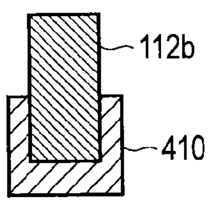


FIG. 4

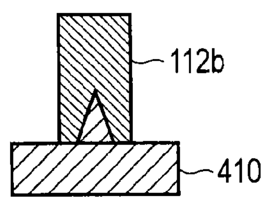


FIG. 5

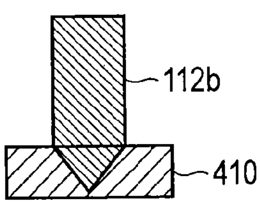


FIG. 6

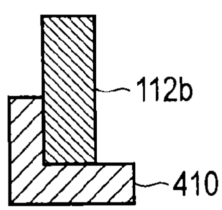


FIG. 7

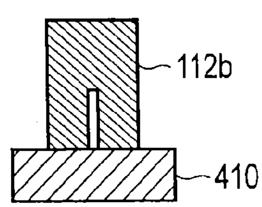
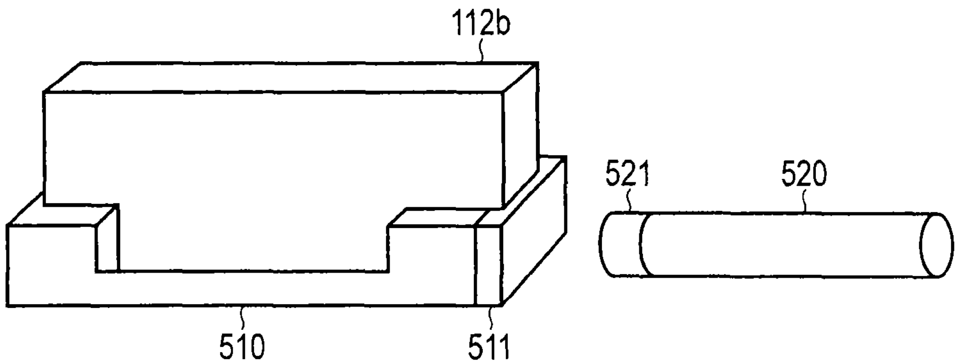
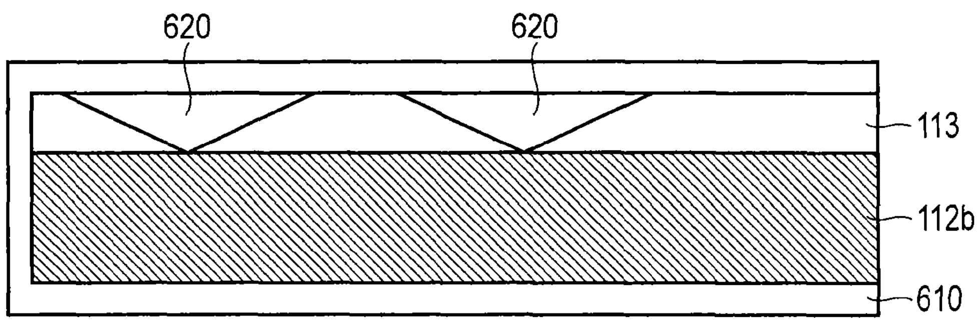


FIG. 8



F I G. 9



F I G. 10

LASER ION SOURCE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2012-043816, filed Feb. 29, 2012, the entire contents of which are incorporated herein by reference.

FIELD

Embodiments described herein relate generally to a laser ion source that generates ions by irradiation of a laser beam.

BACKGROUND

In recent years, a therapy method for cancer by high-energy carbon ion irradiation has been developed and a therapy using an ion source that generates an ion beam has been disclosed.

For advanced performance improvement of the ion source, a high-density C^{6+} needs to be generated. However, for example, since an ion source using μ-wave discharge plasma is lack of capability to generate the high-density C^{6+}, development of a new ion source is required.

Therefore, a laser ion source having an ability to generate a high-density ion beam has been known. The laser ion source is a device that collects and irradiates a laser beam onto a solid target set in a space that satisfies a predetermined vacuum condition, ionizes the solid target by energy of the laser beam, and electrostatically extracts the ions to generate an ion beam.

A feature of the laser ion source is that the solid target is used as a generation source of the ion. By using the solid target as such, high-density ion current can be extracted in the laser ion source.

However, in the case where the laser ion source is continuously operated, the generation source of the ion (that is, the solid target) needs to be supplied in the laser ion source.

For example, in the ion source using the discharge plasma, gas may be just supplied as the generation source of the ion. In this regard, in the laser ion source, the solid target is generally supplied (exchanged) by releasing the laser ion source to the atmosphere whenever supplying the generation source of the ion (that is, the solid target).

When the laser ion source is applied to a medical service, since a long stabilizing operation is required for the corresponding laser ion source, the target is required to be supplied (exchanged) without damaging the vacuum condition in the space where the solid target (hereinafter, simply referred to as a target), which is the ion generation source is set.

In other words, it is important to establish a consecutive supply method of the target which does not significantly damage the vacuum condition in the laser ion source.

However, when the laser ion source is released to the atmosphere whenever supplying the target, the vacuum condition in the space, where the target is set, is damaged.

Therefore, in the laser ion source, a special device is required to supply the target.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a sketch illustrating a schematic configuration of a laser ion source according to a first embodiment of the invention;

FIG. **2** is a side view for describing an operation when supplying a target in a laser ion source according to the embodiment of the invention;

FIG. **3** is a side view for describing an operation when supplying a target in a laser ion source according to a second embodiment;

FIG. **4** is a cross-sectional view illustrating an example of a combination of a supplying target and a guide rail;

FIG. **5** is a cross-sectional view illustrating an example of a combination of a supplying target and a guide rail;

FIG. **6** is a cross-sectional view illustrating an example of a combination of a supplying target and a guide rail;

FIG. **7** is a cross-sectional view illustrating an example of a combination of a supplying target and a guide rail;

FIG. **8** is a cross-sectional view illustrating an example of a combination of a supplying target and a guide rail;

FIG. **9** is a sketch illustrating an example of a target holder and a transportation rod used in a laser ion source according to a third embodiment of the invention; and

FIG. **10** is a schematic diagram illustrating an example of a fixation mechanism that fixes a target used in a laser ion source according to a fourth embodiment of the invention.

DETAILED DESCRIPTION

Hereinafter, embodiments of the invention will be described with reference to the accompanying drawings. According to one embodiment, in general, there is provided a laser ion source, including: a vacuum chamber which is vacuum-exhausted and in which a target generating ions by irradiation of a laser beam is transported and set; a valve which is provided on a side of the vacuum chamber, and is opened when the target is transported into the vacuum chamber and is closed except for the transportation; a target supply chamber which is attached to the vacuum chamber via the valve, holds the target to be movable, and is vacuum-exhausted independently from the vacuum chamber; and a transportation unit which transports to the vacuum chamber the target held on the target supply chamber while opening the valve after the target supply chamber is vacuum-exhausted while closing the valve.

(First Embodiment)

FIG. **1** is a sketch illustrating a schematic configuration of a laser ion source according to a first embodiment of the invention.

A laser ion source **100** illustrated in FIG. **1** includes an ion generation vacuum chamber **110**, a target supply chamber **120**, and a valve (gate valve) **130**.

A target shifting device **111** is provided in the ion generation vacuum chamber **110**. A target **112** containing an element, which becomes an ion, is transported and set on the target shifting device **111**. The target shifting device **111** serves to shift the target **112** so as to change an irradiation position of a laser beam to the target **112**. Further, the target **112** is, for example, a carbon based plate-like member.

In addition, although not illustrated in FIG. **1**, the ion generation vacuum chamber **110** includes an optical system that collects a laser beam **200** on the surface of the target **112**, an acceleration electrode that accelerates the generated ion, and an exhaust system for vacuum-exhausting the ion generation vacuum chamber **110**.

The target supply chamber **120** is attached to the ion generation vacuum chamber **110** via the valve **130**. The target supply chamber **120** is able to be vacuum-exhausted by the exhaust system (not illustrated), independently from the ion generation vacuum chamber **110**.

The valve **130** is provided in a part (a side) of the ion generation vacuum chamber **110** and serves to open/close a flow channel between the ion generation vacuum chamber **110** and the target supply chamber **120**. The valve **130** is opened when the target is transported into the ion generation vacuum chamber **110** and closed except for the transportation, for example. Further, in the valve **130**, for example, opening/closing is performed by a vacuum cut-off valve.

According to the laser ion source **100**, the laser beam **200** is collected and irradiated onto the target **112**, and as a result, an ion **300** is generated by energy of the laser beam and the ion **300** is electrostatically extracted, and as a result, an ion beam is generated.

In detail, in the laser ion source **100**, the laser beam **200** is collected and irradiated onto the target **112** set in the ion generation vacuum chamber **110**, and as a result, a minute fraction of the target **112** becomes hot as a high temperature, is made into plasma, and is emitted to a space, at a point (hereinafter, referred to as an irradiation point) onto which the laser beam is collected and irradiated. Ions in the plasma receive energy even from the laser beam **200**, and as a result, multi-charged ions are generated. In the laser ion source **100**, the generated ion **300** is accelerated in the acceleration electrode to be extracted as a high-energy ion beam.

Further, since the high-energy laser beam **200** is collected and irradiated onto the target **112**, a crater is formed on the surface of the target **112** by one laser irradiation. For stabilization of ion generation in the laser ion source **100**, the laser beam **200** may be irradiated onto a new surface of the target **112** whenever the laser beam **200** is collected and irradiated. To this end, in the laser ion source **100**, the target **112** may be shifted little by little so as to avoid an irradiation point (the point onto which the laser beam **200** is collected and irradiated) which has been used, by the target shifting device **111**.

Further, the center of ablation plume, which is ejected when the laser beam **200** is collected and irradiated onto the target **112**, is a normal direction of the irradiation point (irradiation surface). That is, the surface of the target **112** at the irradiation point of the laser beam **200** is set such that a normal erected from the irradiation point matches an axial direction (a direction to generate the ion **300**) which is mechanically determined in the laser ion source **100**. Hereinafter, the axis, which is mechanically determined in the laser ion source **100**, is referred to as an ion axis.

For example, in the case where the laser beam **200** is irradiated onto all surfaces of the target **112** by little by little shifting the target **112** with the target shifting device **111** as described above, the target **112** set in the ion generation vacuum chamber **110** (on the target shifting device **111**) needs to be exchanged (that is, a new target **112** needs to be supplied).

Hereinafter, referring to FIG. **2**, an operation when supplying the target **112** in the laser ion source **100** according to the embodiment will be described. Further, FIG. **2** is a side view illustrating the laser ion source **100** illustrated in FIG. **1** from a generation (emission) direction of the ion **300**. In addition, in FIG. **2**, a transportation system and an acceleration electrode of an ion of the laser beam **200** are omitted.

Herein, a case in which all surfaces of a target **112***a* set in the ion generation vacuum chamber **110** are collected and irradiated by the laser beam **200** (that is, a case in which the target **112***a* needs to be exchanged) is assumed. In this case, it is assumed that the ion generation vacuum chamber **110** is vacuum-exhausted by a vacuum exhausting device **140** provided in the ion generation vacuum chamber **110**. Further, it is assumed that the valve **130** is in a closed state (hereinafter, referred to a closed state).

Hereinafter, the used target **112***a*, which is exchanged, is referred to as the used target **112***a*.

In this case, the target supply chamber **120** is vacuum-exhausted by a vacuum exhausting device **150** provided in the target supply chamber **120**.

Subsequently, after the valve **130**, which connects the ion generation vacuum chamber **110** and the target supply chamber **120**, is in the opened state (hereinafter, referred to as the opened state), the used target **112***a*, which is set in the ion generation vacuum chamber **110**, is drawn up to the target supply chamber **120** by, for example, a transportation rod inserted into the ion generation vacuum chamber **110** from the target supply chamber **120**.

Thereafter, the valve **130** is in the closed state and the target supply chamber **120** is released to the atmosphere. The used target **112***a*, which is drawn up to the target supply chamber **120**, is exchanged with a target **112***b* (hereinafter, referred to as a supplying target) which is newly supplied into the ion generation vacuum chamber **110**. As a result, the supplying target **112***b* is held (set) in the target supply chamber **120** to be movable. A front end of a transportation rod **121** (a rod-shaped member) is attached to the supplying target **112***b*. Further, a target transporting device **160** for transporting the supplying target **112***b* to the ion generation vacuum chamber **110** is connected to the other end of the transportation rod **121**.

In addition, since the valve **130** is in the closed state as described above, the ion generation vacuum chamber **110** is maintained in a vacuum-exhausted state even during an operation in which the supplying target **112***b* is set in the target supply chamber **120**.

In the case where the supplying target **112***b* is set in the target supply chamber **120** as described above, the target supply chamber **120** is vacuum-exhausted by the vacuum exhausting device **150**.

Subsequently, the valve **130** is in the opened state at the time when an internal pressure of the target supply chamber **120** is equal to or lower than an internal pressure of the ion generation vacuum chamber **110** by vacuum-exhaustion of the vacuum exhausting device **150**, and the supplying target **112***b* is transported into the ion generation vacuum chamber **110** by the target transporting device **160** and the transportation rod **121**.

Herein, the target shifting device **111** is provided in the ion generation vacuum chamber **110** as described and a target shifting stand **113** is installed in the target shifting device **111**.

The supplying target **112***b* transported to the ion generation vacuum chamber **110** is fixed to the target shifting stand **113** and shifted with high precision by the target shifting device **111** such that the normal direction of the irradiation point (irradiation surface) matches the aforementioned ion axis direction.

That is, when the supplying target **112***b* is supplied in the laser ion source **100** according to the embodiment, the valve **130** is in the closed state while the ion generation vacuum chamber **110** and the target supply chamber **120** are in the vacuum exhaustion state and only the target supply chamber **120** is released to the atmosphere. When the supplying target **112***b* is set in the target supply chamber **120**, the target supply chamber **120** is vacuum-exhausted again and thereafter, the valve **130** is in the opened state and the supplying target **112***b* is transported into the ion generation vacuum chamber **110**. As a result, the supplying target **112***b* may be supplied to the ion generation vacuum chamber **110** without releasing the ion generation vacuum chamber **110** to the atmosphere.

Further, the target shifting device **111** provided in the ion generation vacuum chamber **110** includes, for example, an electric actuator. In the case where a motor of an electric actuator is installed in the ion generation vacuum chamber **110**, power is supplied from the outside of the ion generation vacuum chamber **110** and rotation of the motor is controlled. In addition, (A surface of) the target **112** installed in the ion generation vacuum chamber **110** may be in a surface vertical to the ion axis which is mechanically determined in the laser ion source **100** and a shifting direction of the target **112** by the target shifting device **111** may be one direction or two directions.

In addition, the target **112** may be shifted by a linear introducer which is operable from the outside of the ion generation vacuum chamber **110** or shifted by a rotational introducer which is operable from the outside of the ion generation vacuum chamber **110** and a gear installed in the ion generation vacuum chamber **110**.

As described above, in the embodiment, it is possible to supply the target **112** without damaging the vacuum condition by the configuration to include the ion generation vacuum chamber **110** vacuum-exhausted, in which a target generating ions by irradiation of the laser beam **200** is transported and set, the valve **130** provided on the side of the ion generation vacuum chamber **110**, and opened when the target **112** is transported into the ion generation vacuum chamber **110** and closed except for the transportation, the target supply chamber **120** which is attached to the ion generation vacuum chamber **110** via the valve **130**, holds the target **112** to be movable, and is vacuum-exhausted independently from the ion generation vacuum chamber **110**, and the target transporting device **160** which transports to the ion generation vacuum chamber **110** the target **112** held on the target supply chamber **120** while opening the valve **130** after vacuum-exhausting the target supply chamber **120** while closing the valve **130**.

Further, in the embodiment, the target **112** (**112***a* and **112***b*) of a quadrangular prism (plate-like member) is used as illustrated in FIGS. **1** and **2**, but the target **112** may be a polygonal prism other than the quadrangular prism and may be shaped like, for example, a cylinder.

(Second Embodiment)

Subsequently, a second embodiment of the invention will be described with reference to FIG. **3**. In FIG. **3**, the same reference numerals refer to the same element as FIG. **2** (and FIG. **1**) and a detailed description will be omitted. Herein, elements different from those of FIG. **2** will be primarily described.

Further, FIG. **3** is a side view illustrating a laser ion source **400** from a generation (emission) direction of the ion according to the embodiment.

As illustrated in FIG. **3**, in the laser ion source **400** according to the embodiment, a guide rail **410** is installed from a target supply chamber **120** to the ion generation vacuum chamber **110**. The guide rail **410** is provided to define a transportation direction of a supplying target **112***b*. Further, the guide rail **410** is divided at the position of a valve **130** so as not to interrupt opening/closing of the valve **130**.

In the embodiment, the guide rail **410** is provided, and as a result, the supplying target **112***b* is transported to an ion generation vacuum chamber **110** along the guide rail **410**. Therefore, the supplying target **112***b* is accurately mounted on a target shifting stand **113** installed in a target shifting device **111**.

Further, the supplying target **112***b* and the guide rail **410** in the embodiment may be used by a combination of structures in which the supplying target **112***b* is certainly transportable in a stable state.

Herein, FIGS. **4** to **8** illustrate an example of a combination (that is, an attachment method) of the supplying target **112***b* and the guide rail **410**. Further, FIGS. **4** to **8** are cross-sectional views of the supplying target **112***b* and the guide rail **410** on a surface vertical to a traveling direction of the supplying target **112***b*.

As illustrated in FIGS. **4** to **8**, the supplying target **112***b* engages in the guide rail **410** according to the structure of the supplying target **112***b*, and as a result, the supplying target **112***b* and the guide rail **410** may be configured so as not to cause positional gap, for example, in a horizontal direction.

Further, since the embodiment is the same as the first embodiment except that the supplying target **112***b* is transported along the guide rail **410**, a detailed description thereof will be omitted.

In the embodiment as described, the supplying target **112***b* may be accurately mounted (transported) onto the target shifting stand **113** in the stable state by the configuration in which the supplying target **112***b* is transported along the guide rail **410** installed from the target supply chamber **120** to the ion generation vacuum chamber **110**.

Further, in the embodiment, by the configuration in which the guide rail **410** is divided at the position of the valve **130**, the guide rail **410** may be avoided from interrupting opening/closing of the valve **130** even in the case where the guide rail **410** is provided.

(Third Embodiment)

Subsequently, a third embodiment of the invention will be described with reference to FIG. **9**. Further, since a schematic configuration of the laser ion source according to the embodiment is the same as that according to the first embodiment, the schematic configuration will be appropriately described by using FIGS. **1** and **2**.

The embodiment is different from the first embodiment in that a supplying target **112***b* is held on a target holder **510** as illustrated in FIG. **9** and the target holder **510** is transported to an ion generation vacuum chamber **110**.

A junction portion **511** of the target holder **510** with a transportation rod **520**, which is illustrated in FIG. **9**, is made of, for example, a magnetic material. Meanwhile, a magnetic field generating device is mounted on a junction portion **521** (that is, a front end) of the transportation rod **520** with (the junction portion **511** with the transportation rod **520** of) the target holder **510**.

By using the transportation rod **520**, the target holder **510** holding the supplying target **112***b* may be magnetically captured (suctioned) to be transported.

Further, the target holder **510** is transported to the ion generation vacuum chamber **110** as described above, and as a result, the supplying target **112***b* is mounted on a target shifting stand **113** provided in the ion generation vacuum chamber **110**.

In addition, since the embodiment is the same as the first embodiment except that the target holder **510** holding the supplying target **112***b* is transported by using the transportation rod **520**, as illustrated in FIG. **9**, a detailed description thereof will be omitted.

In the embodiment as described above, it is possible to improve stability of a supply operation of the supplying target **112***b* by the configuration in which the target holder **510** holding the supplying target **112***b* is provided and the target holder **510** is transported to the ion generation vacuum chamber **110**.

Further, in the embodiment, the junction portion **511** of the target holder **510** is made of the magnetic material, but the entirety of the target holder **510** may be made of the magnetic material.

Further, in the embodiment, the junction portion **511** of the target holder **510** is made of the magnetic material and the magnetic field generating device is mounted on the junction portion **521** of the transportation rod **520**, but a dielectric is used in the junction portion **511** of the target holder **510** instead of the magnetic material and an electrostatic system may be generated in the junction portion **521** of the transportation rod **520**. In this case, the target holder **510** holding the supplying target **112***b* may be electrostatically captured (suctioned) to be transported.

In addition, in the embodiment, the junction portion **511** of the target holder **510** is made of the magnetic material and the magnetic field generating device is mounted on the junction portion **521** of the transportation rod **520**, and as a result, the target holder **510** is magnetically captured, but for example, the transportation rod **520** is used when the target holder **510** is transported into the ion generation vacuum chamber **110**, while the target holder **510** may be mechanically captured by using, for example, a hook, and the like when the target holder **510** is drawn from the ion generation vacuum chamber **110**.

Further, when the target holder **510** is transported in the embodiment, the guide rail in the second embodiment may be used.

(Fourth Embodiment)

Subsequently, a fourth embodiment of the invention will be described with reference to FIG. **10**. Further, since a schematic configuration of the laser ion source according to the embodiment is the same as that according to the first embodiment, the schematic configuration will be appropriately described by using FIGS. **1** and **2**.

The embodiment is different from the first embodiment in that (a target shifting stand **113** provided in) a target shifting device **111** includes a fixation mechanism that fixes a supplying target **112***b*.

The supplying target **112***b* transported to an ion generation vacuum chamber **110** from the target supply chamber **120** as described above is mounted on the target shifting stand **113**. In this case, the supplying target **112***b* needs to be fixed on the target shifting stand **113** such that the normal direction of the irradiation point (irradiation surface) of the supplying target **112***b* onto which a laser beam **200** is collected and irradiated matches the ion axis direction (the axial direction which is mechanically determined in a laser ion source **100**).

Therefore, in the embodiment, a surface **610** (hereinafter, referred to as a reference surface), which is orthogonal to the ion axis, is provided on the target shifting stand **113**, as described in FIG. **10** and for example, the reference surface **610** and the supplying target **112***b* are brought into close contact with each other by, for example, an elastic body **620** such a spring. In other words, the supplying target **112***b* is pressed against the direction of the reference surface **610** by the elastic body **620**. As a result, the surface of the supplying target **112***b* may be fixed to be orthogonal to the ion axis on the target shifting stand **113**.

In the embodiment as described above, it is possible to improve the stability of the generation of the ion beam by the configuration in which the point (irradiation point) of the transported supplying target **112***b* is fixed onto the target shifting stand **113** to be orthogonal to the ion axis direction to generate the ions.

Further, in the embodiment, the supplying target **112***b* is fixed to the target shifting stand **113**, but the target holder holding the supplying target **112***b* as described in the third embodiment is brought into close contact with the reference surface **610** to fix the supplying target **112***b*.

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

What is claimed is:

1. A laser ion source that irradiates a laser beam onto a target, which is transported to and set in a vacuum-exhausted vacuum chamber, the target being ionized by the laser beam, the laser ion source electrostatically extracting ions from the target to generate an ion beam, the laser ion source comprising:

a vacuum chamber which is vacuum-exhausted and in which a target generating ions by irradiation of a laser beam is transported and set;

a valve which is provided on the vacuum chamber, and is opened when the target is transported into the vacuum chamber and is closed except for the transportation;

a target supply chamber which is attached to the vacuum chamber via the valve, holds the target to be movable, and is vacuum-exhausted independently from the vacuum chamber; and

a transportation unit which transports to the vacuum chamber the target held on the target supply chamber while opening the valve after the target supply chamber is vacuum-exhausted while closing the valve,

wherein the transportation unit is configured to transport the target along a guide rail provided between the target supply chamber and the vacuum chamber,

the guide rail has a cross sectional profile that corresponds to the target to engage the target so that no gap exists between the target and the guide rail in a cross-sectional view, and

the guide rail contacts more than one surface of the target so as to not cause a positional gap in a horizontal direction.

2. The laser ion source according to claim **1**, wherein the guide rail is divided at the position of the valve so as not to interrupt the opening/closing of the valve.

3. The laser ion source according to claim **1**, wherein the vacuum chamber includes a target shifting unit which shifts the target to change an irradiation position of the laser beam to the transported target.

4. The laser ion source according to claim **3**, wherein the target shifting unit includes a fixation unit which fixes the target such that a surface of the transported target is orthogonal to a direction to generate the ion.

5. The laser ion source according to claim **1**, wherein the transportation unit transports to the vacuum chamber the target held on the target supply chamber while opening the valve when the pressure of the target supply chamber is equal to or lower than the pressure of the vacuum chamber.

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